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## ERGONOMICS

### TYPES OF SYSTEMIC REPRESENTATION OF OPERATIONAL ACTIVITY

Moscow TEKHNIЧЕСКАЯ ЭСТЕТИКА in Russian No 4-5, 1977 pp 24-26

[Article by Cand Tech Sci N. G. Alekseyev and Psychologist I. N. Semenov, All-Union Scientific Research Institute for Esthetic Styling in Engineering]

[Text] The object of ergonomic knowledge is viewed in all ergonomic theories without exception (and this is extremely important to emphasize) as a complex, integral formation, which through various traditions has acquired a special name--operator work, the "human factor" in technology, "man-machine" systems, and so on. Behind all of the nuances and differences in these different names for the object lies a single concept about the object of ergonomic knowledge as one that is predominantly a system--that is, a hierarchically structured whole, from which we can isolate individual elements, associations, and functions, as well as the environment external to this object, and so on. It is precisely through the object of analysis that we find the grounds for and associate all other questions in the research problem: The terms we use to refer to these objects is always the name of the real activity itself, the reflection of which is our knowledge of that object. Looking at the history of research in ergonomics and engineering psychology, we can distinguish two basic stages and, correspondingly, two types of concepts on the work of an operator: In the first we view such work on analogy with a technical system, and in the second we view it as complexly organized activity.

#### The Technical Approach

The time of inception of engineering psychology, ergonomics, and practical participation of psychologists in "man-machine" system planning (the 1950's) coincides approximately with the time of arisal of other sectors and directions of scientific-technical knowledge--systems engineering, operations analysis, information theory, cybernetics, and so on. It would be important to note that all of the disciplines listed above underwent joint development in the initial stages. Naturally they had a significant influence upon each other, and they made use of many common ideas and concepts. In particular, various ideas of the cybernetic approach enjoyed the dominant role and the most widespread recognition, particularly in research and planning conducted

from the standpoint of engineering psychology. It is easy to understand that the very concept of the basic object of ergonomic analysis--"man-machine" systems (MMS)--was based on the cybernetic system concept.

As an example the works of P. M. Fitts (1,2), devoted to systematizing errors and the distribution of functions between man and machine, had a considerable influence on development of ergonomics. This research did in fact create a precedent, which was then followed in the future and which was the first to be tested out in analysis of pilot error. Errors were defined and classified in accordance with the typological features of both the equipment design and external factors. The main reason this was done was that the laws governing the activity of a pilot-operator had not been subjected to directed research, being studied only from one case to another. Fitts' research can be characterized as the prototype of many subsequent studies. These studies brought into being the basic scheme by which "man-machine" systems are represented, namely a sequence of components: External influence--technical devices--man--responses. The third member of this sequence--"man"--was interpreted as the transforming, mediating link between the others. In this sense he was exactly the same sort of component in the system as were the technical devices (the machine). Following a slight modification, the sequence above can be written as: Influence (input)--system--reaction (output). Even if we drop the details associated with the concepts of feedback and information from this article, the cybernetic nature of this sequence is blatantly obvious.

We should note that it is easy to use the entire paradigm of systems categories and concepts within the framework of such schemes: The delimited nature of the whole and its priority in relation to its components, external and internal environment, the concept of function as a special relationship between input and output, and so on. It is no accident that research of this type is treated as systems analysis (3).

The approach Fitts outlined enjoyed its fullest development in his analysis, which has become classical, of the distribution of functions between man and machine, and since that time it has had and continues to have a significant influence on specific ergonomic projects. The work of a system is analyzed from the standpoint of its completion by one component or the other--man or a technical device. Using the "input-output" concept we can list the possible functions which do in fact define the work of the system or its behavior. Next we determine which component of the two could perform the given function better.

Let us analyze the principles behind such research in greater detail. First of all we should emphasize that these principles are wholly within the mainstream of the ideas of correctional ergonomics. The basic objective of the research is to make the activity of an operator more efficient under given conditions (both when analyzing errors and when listing functions with the purpose of their subsequent distribution). The possible conditions must be fully defined. As a starting point we plan a "rigid" system defined by the nature of potential "inputs."

Second, the scheme used to analyze concrete forms of activity is closely associated with the ideas of correctional ergonomics. Using the "black box" idea, in the cybernetic approach we in fact avoid the problem of analyzing (in the particular case of analysis) the internal laws governing the object's activity. However, we cannot completely ignore analysis of activity in this approach. In this case activity is viewed as a unique form defined by the "normal-deviation" relationship. Consistency between input and output (absence of error, the component within the system performs its function) is defined as normal. Inconsistency between input and output is defined as a deviation (the error factor is sought, the function is transferred to another component). We should note in this connection the basic empirical orientation of such an approach as a whole, which once again graphically confirms its association with correctional ergonomics.

Third, the need for complete collection of empirical data (in relation to the "inputs") follows from the previous principle. This requirement is the main prerequisite for subsequent determination of the system of factors governing the effectiveness of the action of the system as a whole. This predetermines many of the methods of ergonomic research on and planning of a man-machine system viewed mainly as a "technical" system.

Fourth, the unit of analysis in this approach is the function which is defined (not in the mathematical aspect) as a certain type of "input-output" transformation (2). From this point of view the system itself takes the form of the set of such functions.

Fifth, the effectiveness of the system as a whole is determined in connection with the fourth principle. Isolation of individual functions and representation of the system as the set of these functions inevitably lead to "additive synthesis": The effectiveness of the whole is viewed as an additive function (now in the mathematical sense) of the effectiveness of its components. Moreover, the essence of the matter changes in no way if we ascribe certain relative weights to the individual components as coefficients.

Sixth, from a methodological standpoint the concept of a system as something "technical" is synonymous with the concept of additive synthesis. The essence of such a system is expressed as a rule in matrix form, and then correlations between individual variables are computed; the resulting correlation matrix is used in dispersion, factor, and other forms of statistical analysis.

Seventh, we should lay special emphasis on the following characteristics of this approach: The factors isolated in the end are linearly independent; this by itself excludes the special objective of studying the mechanisms behind their real association (this exclusion follows from the very method of data collection). Such study is displaced and substituted by the use of mathematical machinery.

Thus this view of an MMS as a technical system generally involves an empirical-procedural orientation toward our understanding of the nature of the man-machine system, and factorial (tabulated, listed) representation of

activity. This concept of an MMS follows from the orientation of the terminology of behavioral cybernetics (4,5).

Ergonomic planning encounters real difficulties when an MMS is interpreted as a technical system. The empirical orientation results in description of particular cases. The very process of searching for a prototype becomes nonproductive as the number of such cases grows (due to absence of knowledge of the laws behind operator activity in the MMS). This is the root of the shortcoming of this approach: When the analyst sets the rules for organizing the research he fails to comply with the principle of "seeing" (the structure of) the object, the initial object he is attempting to represent. The subject (the analyst) never makes the object explicit through its individual features.

We could name other shortcomings of this approach, but we should not forget that representing an MMS as an essentially technical system had (and even has today) a fully meaningful purpose. Many interesting methods have been developed through this approach, and our task today is to assimilate these methods at the new level of development of ergonomics.

#### The Activity Approach

While in the technical definition of an MMS the work of the individual existing as a component within the system is represented as one of input-output transformation, in the activity approach we change the initial premise itself. What becomes most important is to study the nature and structure of activity performed by man, which we had excluded earlier. This of course does not mean that we now exclude, from our MMS scheme, components such as inputs (stimuli, influences) and outputs (reactions, responses). We simply view the system from a different standpoint: These components become the inputs and outputs of the whole, which has a complex internal organization and structure, which we can no longer ignore in our analysis. Thus analysis and planning of a "man-machine" system experiences evolution, from expulsion of the system's inner workings to their postulation and analysis.

Ergonomic research was oriented in our country toward studying the laws governing operator activity from the very beginning of its development. This is easy to explain: On one hand the initial problems of this research were formulated within the mainstream of research in engineering psychology, while on the other hand ergonomic research relied upon the traditions of the activity approach to studying the mind and mental processes, the traditions which had evolved in Soviet psychology by that time (6,7,8).

Use of such concepts as the structure and its elements, the dependence of the elements upon the whole and presence of special, specific properties in the whole that cannot be reduced to the properties of its elements, which have functional associations, the concept of hierarchical levels, and so on--that is, practically the entire paradigm (set) of concepts used in the systems approach--had been restricted in research on operator activity.

Being a general scientific methodological orientation, the system approach naturally made its way into ergonomic theory and practical research. As the systems orientation was introduced, the approach to research on operator activity began to undergo continuous alteration: Researchers began to turn their awareness from isolated concepts of the systems approach to the entire paradigm of concepts as a whole, to the specifically systemic association among these concepts. Within ergonomics we combine both samples of concrete systems research and theoretical work which analyzed this research, particularly from the standpoint of utilizing the principles of the systems approach within it (9,10). Because this is as far as the evolution has proceeded, we can discuss only some problems of a methodological order in this article.

The first among them, first posed by E. G. Yudin (11) in the methodological aspect, is the problem of the relationship among general (philosophical, general scientific) principles and the ways and means by which they are made specific to and used in concrete theories. Thus we cannot represent activity (operator activity from a narrower standpoint) as a systemic object simply by applying the systems orientation on its own, by the simple act of applying this orientation to any arbitrarily chosen representation of activity. The systems orientation is only one of the necessary prerequisites (and resources) for building such an object. The situation is precisely the same with the activity orientation as well. When viewed as a general philosophical principle or as an initial premise for psychology as a whole, as in the first case it is a necessary prerequisite and resource, and by itself it cannot lead us to the structure of a systemic object. Something specific must always be added--a special subjective view of the object. Of course we do not mean any subjective view, but rather one which responds to the essence of the research. By closing the circle of methodological orientations (systems and activity) with a subjective view of the object we represent the structure of activity as a systemic object (12).

The logic of transformation--expansion and refinement--of the conceptual scheme of activity developed by A. N. Leont'yev and used in ergonomic research becomes understandable in light of the above. Using this scheme, which was created with the purpose of explaining the origin of the mind, it was found to be difficult and sometimes practically impossible to explain empirically isolated laws of operator activity chiefly because the scheme itself ended with representation of an operation (an action made automatic) as the last unit of psychological analysis. That "specific thing that was added"--the new subjective view--was postulation of the presence of short-term processes into which the operation could be "expanded." By closing the circle of the methodological orientations (systems and activity) with this subjective view we created a new systemic construct--the functional unit. It would be interesting to note that introduction of functional units made it possible to reveal a number of new mechanisms in the transition from an action to an operation, and to describe these constructs qualitatively. Work (9) is classical in this regard.

This leads to the thought that it might be possible to introduce another systems construct--something "between" activity and action, as defined by A. N. Leont'yev. Both components of his scheme are not limited in any way, and in this sense they could be "stretched" to any size (such distinction, this need for boundaries was not significant to solving the general psychological problem for which this scheme had been created). At the same time, boundaries of greater distinctness will have to be established if ergonomics is to study intellectual processes such as problem solving, decision making, and so on. An interesting analogy with this can be found in psycholinguistics, in which an addition similar in many ways to the one becoming visible here was made--namely the introduction of a new unit--"superphrasal unity"--intermediate between "text" and "sentence," the traditional units of linguistic analysis.

We can note another trend in the use of systems ideas which is now clearly seen in both Soviet and foreign ergonomics. Perhaps it could be described most clearly as a shift occurring from a general functional understanding of a system to its "organismic" interpretation. This shift is occurring both in our understanding of the specific features of the "man-machine" system and in the way the essence of operator activity is represented.

Here as an example is what M. de Monmollen, a prominent French ergonomist, writes in one of his book's chapters titled very symptomatically "MMS as Organisms": "A broader and more substantial definition of MMS is being proposed in the most recent ergonomic works, especially in Europe. MMS are viewed as 'open systems' as defined by Bertalanffy. Models used in analysis of MMS are no longer relatively static models subdividing the system into elements and the associations between them. The concepts of activity, adaptation, homeostasis, self-organization, regulation, and so on are used to describe the dynamic aspects of MMS" ((13), p 228).

So it is similar with research on the laws governing operator activity. When we conduct integrated research on the development of actuating skills, making use of the entire set of microgenetic, microstructural, and micro-analytical methods, we reach a definition of action as some sort of "living" organization, and then as a functioning organism, and if the action is examined within a system of other actions, then the action is defined as an organ.

One of the consequences of this trend in ergonomics is, in our opinion, higher interest toward such types of systems as open, self-organizing, and goal-oriented systems (3,13-15).

Thus application of the principles of the systems approach in ergonomics was examined in this article from a specific (methodological) point of view. We analyzed the shift occurring in our understanding of its object, the transition from viewing a "man-machine" system as a technical system structured according to the principle of "input-output transformation", to an approach in which we view activity, an approach placing its focus on analysis of the internal laws governing man's actions in a complex technical system.

This can be seen especially well in the shift in focus of research on human actions. While in earlier psychological research on labor the latter was typically defined as a process and the stages of this process were revealed and defined (in terms of their duration, completeness, and so on), now with the systems orientation this scheme is no longer initial and basic (2,4,16). Now the structure of activity (that is, its organization, levels, and so on) is in the center of attention. This presupposes a new definition of the action itself as a multicomponent formation, in which each component has its own specific functions within the single action, and so on. We find that these systems themselves (that is, actions, which are now defined as systems) are also different. This necessarily leads to discrimination of different systems--that is, to definition of special forms and types of systems.

What we are referring to is the classification of operator activity suggested in works by V. P. Zinchenko, V. M. Munipov, and others (9,10,17). These studies revealed four basic types of operator work (the activity of an operator-executive, an operator-process engineer, an operator-observer, and an operator-researcher) depending on the basic function being performed, and two forms of relationships--the relative weights of the figurative and conceptual components of human activity, and the proportions of labor carried out by man and the machine. By switching to systems analysis of the internal structure of each type of work we gain a possibility for planning a number of the laws of future forms of activity which are presently just on the drawing boards, *a priori* in a sense.

We have briefly described two of the most widespread ways for representing operational activity as a system. Deeper analysis of these forms would lead us to a broader range of methodological problems associated with the development of ergonomic theory and practice.

As an example by analyzing the structure and function of ergonomic knowledge, the typological aspects of aggregate ergonomic activity, and a number of other similar methodological problems we can more clearly establish and distinguish the limits of applicability of the systems approaches examined above in ergonomics, explain the general conditions of their operation and their "reproduction," and predict their potential future.

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## ERGONOMICS

### OPERATOR FUNCTIONAL STATE DIAGNOSTIC UNIT

Moscow TEKHNIЧЕСKAYA ESTETIKA in Russian No 4-5, 1977 pp 27-28

[Article by Cand Psych Sci V. K. Kalin, Cand Psych Sci V. V. Mironenko, and Engineer A. N. Frantsev, Simferopol' State University, and Cand Psych Sci V. G. Romanyuta, VNIITE]

[Text] A computer method for assessing functional states on the basis of psychometric tests was proposed and tested in research by A. B. Leonova. Use of a Dnepr-1 electronic computer made it possible to obtain quick information on functional states of an operator (1). The proposed method has microstructural analysis of cognitive short-term processes as its theoretical basis (2,3). Testing by this method requires six types of assignments, dosed in relation to the quantity and presentation rate of information, to be completed by the subject: Reproduction of a presented number at maximum speed (by pressing the appropriate key on a console); search for a required number in a sequence of numbers presented one after another at the same point within the field of vision; recognition of a number communicated to the subject after a sequence of numbers is presented; transposition of a random sequence of numbers into a natural series of numbers and detection of the absent number; complete reproduction of a presented series of numbers; complete reproduction of a presented series of numbers after completing an interfering task.

This method imposes the following requirements on the way the information is presented and the way the subject's responses are recorded: Numerical stimuli must be displayed for 10 msec; interstimulus intervals must be within 30-600 msec; the latent and motor periods of the subject's reactions must be measured with a precision of up to 1 msec. The correctness of the subject's responses must be determined.

The results of research performed on this method showed it to be promising. At the same time far from all scientific research and applied ergonomic laboratories have the computer technology and could conduct experimental research with a computer.

Moreover, use of standard computers is not always suitable because they occupy a large amount of space, the use coefficient of the equipment is low, the need for service personnel is large, and because the cost of the computer itself or rental of computer time is very high. This is why the problem of developing specialized, maximally portable experimental units intended for theoretical and practical goals continues to be acute.

A specialized unit making it possible to impose a dosed mental load and assess the functional state of an operator in a way similar to the way such states are assessed in work was developed by the VNIITE [All-Union Scientific Research Institute for Esthetic Styling in Engineering] jointly with the Simferopol' State University (1).

Significant difficulties are encountered in attempts to standardize the conditions of mental work, since the special capabilities and skills of the subjects have an effect on the work results. One of the possible ways to solve this problem is to select sufficiently simple activity from which the possibility of memorizing the work results would be excluded, and with which the subjects would have approximately the same amount of experience. Arithmetic using digits up to 10 coupled with elementary operations in comparing the presented numbers was selected as this sort of work. A similar method has already been used to study mental efficiency (4,5).

The variant of the method we selected involves the following: A series of single-digit numbers is presented to the subject on a display panel in the same point within his field of vision. The subject must compare each succeeding number with the previous one, which he must retain in his memory. If the preceding number was larger than the one presently on the panel, the subject must compute the difference between the two numbers, while if the preceding number was smaller than that presently on the panel, he must find their sum.

The diagnostic unit permits organization of mental work in two modes:

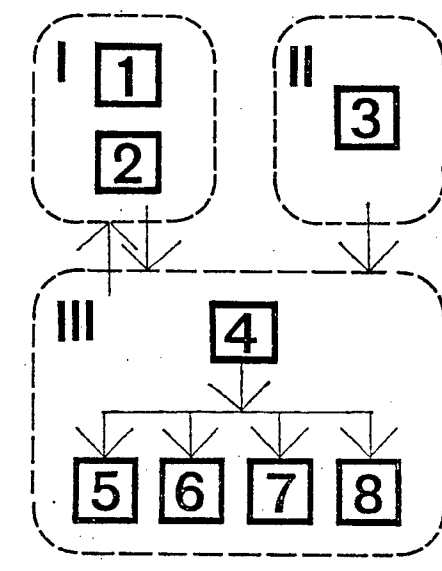
With the presentation rate of numbers on the panel set by the experimenter (the subject's failure to perform a current arithmetic operation was treated as an error);

with the work rate set at maximum for each subject (in this mode, numbers on the panel must be changed immediately after the subject presses his answer recording key).

The selected form of mental work cannot be thought of as close in psychological content to the work of an operator in an automatic control system, but it doubtlessly affords a possibility for standardizing the experimental conditions and dosing the mental load.

We can assess the specific features of the mental efficiency of the subjects on the basis of the time required to perform the arithmetic operations and the number of errors made.

The experimental unit we developed and designed (see figure) consists of three basic blocks--the subject's console, the experimenter's console, and the information display and processing block.



Structural Diagram of the Diagnostic Unit: *I*--Subject's console; *II*--experimenter's console; *III*--information display and processing block; 1--display panel; 2--key panel; 3--panel on experimenter's console; 4--information input device; 5,6,7,8--correspondingly the first, second, third, and fourth working channels.

Information is presented to the subjects on a light signal panel by means of eight-segment digital electroluminescent indicators (ELI), the height of which in relation to the eye level of the subjects can be adjusted. The subject faces a panel bearing keys for all variants of responses encountered with this method for working with the unit.

The panel of the experimenter's console has buttons and tumbler switches with which he can control the device during the experiment.

The information display and processing block is the most complex part of the experimental unit, and it consists of four information input devices and four working channels.

Information is carried on punched paper tape, on which the programs of the various methods are punched. Two tape-winding mechanisms furnished with photo inputs govern the lengths of presentation times and interstimulus intervals, which can be varied additionally by changing the dimensions and mutual locations of the punched holes. In addition to tape-winding mechanisms the information input block includes a shaper, the output signals of which,

after being amplified and corrected to standard form, support normal work of all of the device's other units.

The first working channel presents information to the subjects on his light signal panel simultaneously as it is read from the punched tape. This channel is used when testing the functional blocks of visual information processing.

The second channel performs the functions of processing and recording the subject's responses. Its main task is to store the information obtained from the punched tape until the subject presses a key. At the moment the subject presses any one of the keys the answer is compared with the number stored in the operational memory, and the response is recorded (as right or wrong) by an N-30 recorder in the form of pulses of different polarities; the numbers of right and wrong answers are also recorded in a counter.

The third working channel is used when the subject does mental work (elementary operations of comparing certain given numbers within 10). If in the sequence of one-digit numbers the previous number is greater than the one presently on the light signal panel, the subject must compute their difference, while if the preceding number is lower he must find their sum, and then press the appropriate key. The responses are recorded.

The rate at which the subject must perform mental work, both forced (identical for all subjects) and maximum for each subject, is set by selecting the corresponding distances between poles on the punched tape using an automatic (with a service signal) and a manual (from the subject's console and the experimenter's console) punched tape advance on/off control system.

The fourth channel is similar in layout to the first and can be used when complex stimuli must be presented to the subject.

A successive reaction measuring unit with its output connected to an EMU-23 digital reading device is used to determine the temporal parameters of the subjects' responses. The subjects' right and wrong answers are recorded by ChZ-30 frequency meters; the ELI are powered (220 volts, 400 Hz) by a GZ-33 acoustic generator through a step-up transformer.

Use of relatively inexpensive, standard, industrially produced instruments for information input, to power the ELI, and to measure and record the temporal parameters of the subjects' responses reduces the task of creating the diagnostic unit to building the information display and processing block, which can be done in the laboratory.

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## ERGONOMICS

### ANALYSIS OF WRONG ACTIONS BY A HUMAN OPERATOR DURING COMPENSATORY TRACKING OF RANDOM SIGNALS

Moscow TEKHNIЧЕСКАЯ ЭСТЕТИКА in Russian No 4-5, 1977 pp 28-30

[Article by Cand Tech Sci A. P. Chernyshev, Moscow Higher Technical School imeni Bauman, and Engineer V. G. Zazykin, USSR Academy of Sciences Institute of Psychology]

[Text] The advantage a semiautomatic system having a human operator as one of its elements has over an automatic system is the possibility for processing previously unforeseen information. This information is a random process. When we subject the functional characteristics of a human operator performing tracking functions to experimental analysis, it is important to analyze the activity of the operator in response to presentation of a random process.

We should note that a tendency toward using a polyharmonic signal as a model of a random presented signal has taken shape in a number of studies (1,2,3). The idea behind this is that the sum of harmonics representing the input signal cannot be predicted by the operator, and that it is random to him. We know, however, that any polyharmonic signal is periodic. The mechanism behind operator prediction has not been studied sufficiently as yet. For this reason there are no grounds for assuming that a polyharmonic signal can be predicted by operators. In any case we do not as yet have persuasive evidence that the sum of harmonics is perceived by an operator as a random process. As an example imagine that a low frequency harmonic and high frequency harmonics are presented additively to the sensory input of the operator as he performs tracking functions. Performing the functions of a high frequency filter, the operator tracks the low frequency harmonic with errors. In this case the high frequency components of the signal could be interpreted as errors in the operator's motor reactions. We should also consider that the question as to the composition and intensity relationships of harmonics in a polyharmonic signal, which could be perceived by an operator as a random signal, has not been resolved as yet. Although this is a rare case, it does persuasively show that we can find examples refuting the assertion that an operator perceives a polyharmonic signal as a random signal.

This work presents the results of analysis of the errors an operator makes during compensatory tracking of a random signal. The signal presented is

a random telegraph signal representing a process randomly assuming one of its two possible values, "+a" and "-a", at zero mathematical expectation. A random telegraph signal is one of the most difficult to track since the rate of stepwise changes in amplitude is infinite; this is why operators were always late in their responses to change in the stimulus (the presented signal). A random telegraph signal has a Poisson distribution (4). Therefore the probability that there would be  $m$  zeros in time interval  $t$  is:

$$P_m(t) = \frac{\lambda^m \cdot t^m}{m!} \cdot e^{-\lambda t},$$

where  $t$  is current time, sec;  $m$  is the expected number of reversals during time  $t$ ;  $\lambda$  is the density of the input signal--that is, the average number of reversals per unit time.

The autocorrelation function of this process can be described by the expression:

$$R(\tau) = a^2 \cdot e^{-2\lambda|\tau|},$$

where  $\tau$  is the correlation interval, sec, and  $a$  is the oscillation amplitude, units.

The random process is stable because  $\lambda$  is stable in time.

The presented signal was shaped by a noise generator. The radioactive element Sr-90, which has a random half-life, was used as the signal source. The current of  $\beta$ -particles struck a Geiger counter, after which it was converted in a flip-flop circuit and, on being amplified, was fed to the screen of a display. The presented signal was tracked by means of a potentiometric control knob having a linear working characteristic. The negative feedback loop used to determine tracking error was shaped by an analog computer. Deviation of the presented signal from its zero position was  $\pm 8$  cm. The distance between the subject's eyes and the screen of the display was 80 cm. The experiment was performed in a soundproofed chamber in electric lighting corresponding to normal daylight with various magnitudes of presented signal density: Small  $\lambda$  is 0.2-0.4 reversals/sec, average  $\lambda$  is 0.5-0.8 reversals/sec, and high density is 1 reversal/sec or more.

The presented signals, the operator's reaction, and the tracking errors were registered by a Poligraf recorder (Figure 1a,b). Due to the random stepwise nature of stimulus changes there was always a delay in the operator's reactions. A decrease in alertness occurs when a random signal of low density is tracked (5), owing to which the delay is rather significant. The delay decreases at high stimulus density (according to (5) this effect can be explained by the fact that as stimulus density increases, more energy passes to the nervous system from the stimulus and, as a consequence, the final

reflex effect is more energetic. The delay of the response begins to grow at greater densities of the presented signal because omissions of pulses begin to occur, and the tracking error grows. Figure 3 shows change in the average delay experienced by an operator tracking random signals of different densities. We should note that a longer delay in reactions of an operator tracking signals of small and large density was also accompanied by greater scatter in  $t_{delay}$  than in the case of tracking a signal of average density. In other words deviation of the density of the presented signals from quasioptimum (from the standpoint of tracking precision) leads to unstable work by the operator. The scatter of the temporal delay of the response's motor component changes similarly.

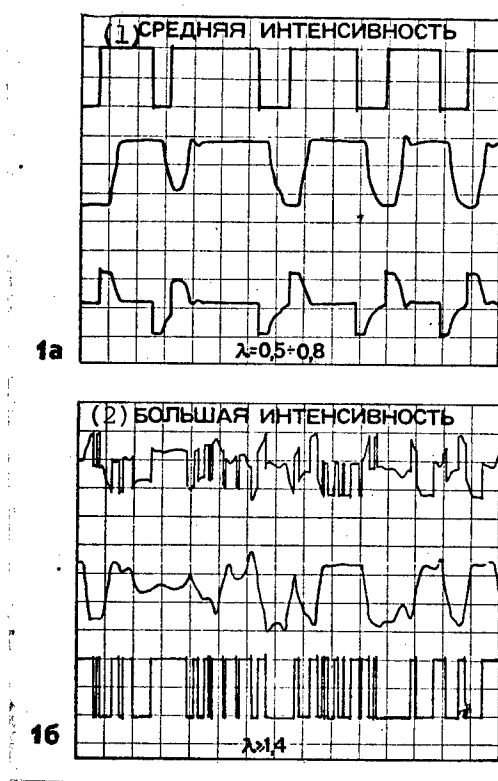


Figure 1. Oscillograms of Experiment Results.

Key:

1. Average intensity
2. Large intensity

The distribution of the tracking error of operators is close to normal for the presented signal densities analyzed. The tracking error asymmetry and excess values differ insignificantly from one another and can be explained by the finite nature of the interval of observation and procedural errors in treating the experimental data. The precision and the nature itself of the process of tracking the random telegraph signal depend mainly on the density of the presented signal. Tracking a small density signal is

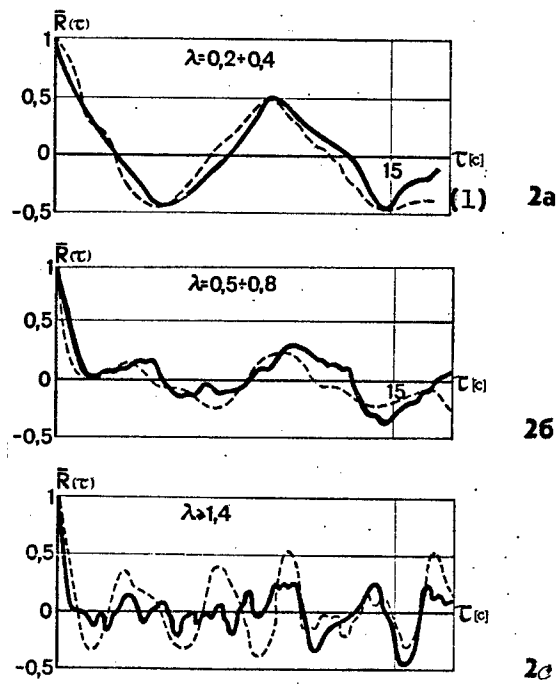


Figure 2. Autocorrelation Functions of the Stimulus and the Operator's Response: Normalized autocorrelation functions: — -- Presented signal, --- --operator's reaction.

Key:

1. sec

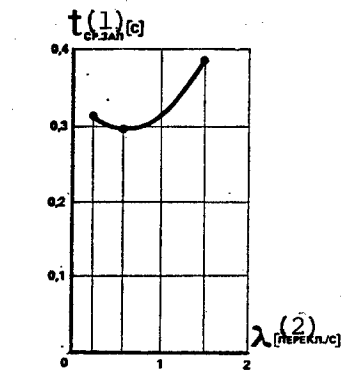


Figure 3. Change in Average Delay Depending on Stimulus Intensity.

Key:

1.  $t_{ave. delay}$ , sec

2.  $\lambda$ , reversals/sec

distinguished by relatively high precision. Pulses of the presented signals are not omitted as a rule, and over-reactions to the stimulus are absent. The autocorrelation functions of the presented signal and the operator's reactions change similarly (Figure 2a).

Tracking of a signal of average density is characterized by lower precision; greater distortion of the stimulus shape occurs, and over-reaction arises in tracking. Significant differences begin to appear in the nature of the autocorrelation functions of the presented signals in relation to the operator's reactions (Figure 2b).

When the operator tracks a signal of large density, significant distortion occurs in the shape of the stimulus, pulses are omitted, and reactions become premature. In a number of cases the operator reacts not to the large density signal itself but to its average. Tracking breaks down with further increase in density ( $\lambda \geq 2.5$ ). The error in tracking a signal of large density is so high that the autocorrelation function of the stimulus differs fundamentally from the autocorrelation function of the operator's reactions (Figure 2c). We should note that the difference between the shapes of the autocorrelation function of the tracking error and the theoretical functions can be explained by the finiteness of the interval of the given experiment. The significant difference between autocorrelation functions of the presented signal and the response of an operator tracking a signal of large density indicates that tracking is nonlinear. A similar result was obtained on analyzing the maximum values of the coherence function for "tracking error--operator's response" signals (Figure 4). As we know (6), the coherence function indicates the nature of input stimulus transformation:

$$\gamma_{er}(\omega) = \frac{|S_{er}(\omega)|^2}{S_{ee}(\omega) \cdot S_{rr}(\omega)},$$

where  $S_{ee}(\omega)$  is the spectral density of the tracking error signal,  $S_{rr}(\omega)$  is the spectral density of the operator response signal, and  $S_{er}$  is the mutual spectral density of error signals and the response.

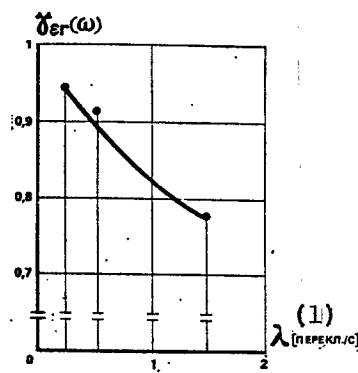


Figure 4. Change in Values of the Coherence Functions of the "Error--Response" System for Different Stimulus Values.

Key:

1.  $\lambda$ , reversals/sec

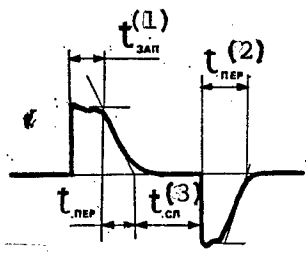


Figure 5. Composition of Tracking Error.

Key:

1.  $t_{delay}$
2.  $t_{trans}$
3.  $t_{tracking}$

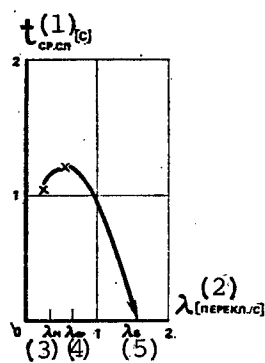


Figure 6. Change in Tracking Time Depending on Stimulus Intensity.

Key:

1.  $t_{ave. delay}$ , sec
2.  $\lambda$ , reversals/sec
3.  $\lambda_{small}$
4.  $\lambda_{ave.}$
5.  $\lambda_{large}$

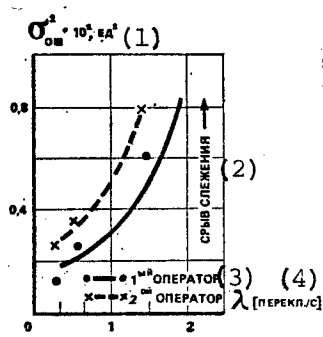


Figure 7. Change in Tracking Error Variance Depending on Presented Signal Intensity.

Key:

1.  $\sigma^2_{error} \cdot 10^2$ , units<sup>2</sup>
2. Breakdown in tracking
3. Operator
4.  $\lambda$ , reversals/sec

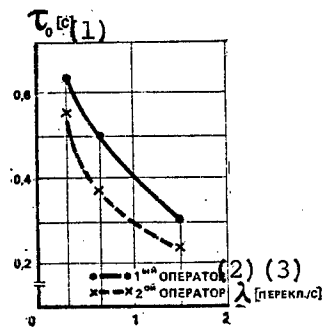


Figure 8. Change in Degree to Which the Tracking Error is Stochastic Depending on Presented Signal Intensity.

Key:

1.  $\tau_0$ , sec
2. Operator
3.  $\lambda$ , reversals/sec

The values of the coherence function vary within  $0 \leq \gamma_{cr} \leq 1$ , this function being equal to unity after linear transformation. Thus when the density of the presented signal is small and average the operator functions for practical purposes as a linear tracking system. In fact, when the density of the presented signal is small or average the tracking error itself consists of a passive part--while awaiting the pulse, and an active part--while processing the presented signal (Figure 5).

In turn, the active part consists of  $t_{delay}$ --the time of the motor delay,  $t_{trans}$ --the time of the transitory process in which the operator works himself into the task, and  $t_{tracking}$ --the tracking time specifically.

As the density of the presented signal increases the time of tracking specifically first begins to grow (until the stimulus density reaches its average value), and then it begins to drop dramatically (Figure 6). Such change is in a sense a consequence of change in the delay of the operator's reactions--that is, the minimum delay in response to average density of stimulus change corresponds to maximum time of tracking specifically.

When the stimulus density increases the tracking error grows. Figure 7 shows change in the variance of the tracking error depending on presented signal density. As the tracking error experienced increases the error undergoes qualitative change, the breadth of the spectrum increases, and its frequency composition changes. This is reflected uniquely by change in the degree to which the tracking error is stochastic--that is, by change in the interval between the coordinate origin and the point at which the autocorrelation curve first crosses the abscissa (Figure 8). The obtained dependencies are similar to those presented in (7), the effectiveness of the use of which has been demonstrated in a number of practical examples.

Thus one of the main factors defining the precision of transitory tracking is the density of the presented signal. Its change elicits change both

in the magnitude of the error and its internal structure on one hand and the very nature of the tracking process of the operator on the other. Change in the structure of the activity of an operator tracking a random telegraph signal of growing intensity can be analyzed effectively by using the coherence function of "tracking error--operator's response" signals.

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## ERGONOMICS

AT THE COORDINATING CENTER FOR THE PROBLEM 'DEVELOPMENT OF THE SCIENTIFIC GROUNDS OF ERGONOMIC NORMS, REQUIREMENTS'

Moscow TEKHNICHESKAYA ESTETIKA in Russian No 4-5, 1977 pp 30-31

[Articles by A. N. Strokina, VNIITE, and L. I. Koncha, VNIITE]

[Text] Report by A. N. Strokina, VNIITE [All-Union Scientific Research Institute of Esthetic Styling in Engineering]

The third meeting of the Scientific-Technical Council on the problem "Development of the Scientific Grounds for Ergonomic Norms and Requirements" was held at the end of 1976 in Budapest (Hungary). The council's work was under the chairmanship of Doctor of Psychological Sciences, Professor, USSR Academy of Pedagogical Sciences Corresponding Member V. P. Zinchenko; the members of the scientific-technical council and colleagues of the Coordinating Center, the CEMA Secretariat, and the Administration for Scientific-Technical Cooperation With Socialist Countries of the USSR Council of Ministers State Committee for Science and Technology took part in the meeting.

During this meeting discussion of the working programs pertaining to the norms and requirements problem was continued, and reports were given on the results of scientific research pertaining to particular assignments.

The working program for the assignment "Development of the Structure, Principles, and Methods of Ergonomics" (USSR) was discussed. In this assignment, the results of methodological analysis of present ergonomic concepts will be reflected, and the basic ideas about the structure, principles, and methods of ergonomics will be systematized and described.

Working programs were also discussed for the assignments "Development of Psychological Criteria" (GDR), "Development of the Methodological Principles for Optimizing Labor and Systems on the Basis of Ergonomic Criteria and Indices" (Romania), "Optimization of Motor Activity During Work in a Seated Posture" (Czechoslovakia), "Development of Standard Terminology in Ergonomic Requirements on 'Man--Machine--Objective Environment--Production Environment' System" (Bulgaria), and "Development of Methods for Assessing Ergonomic Quality of Industrial Articles" (GDR); discussions were also held on programs

for assignments developed by Bulgaria and Czechoslovakia pertaining to the problems of developing ergonomic requirements on technical resources used to display information to a human operator, and other assignments.

The Institute of Technical Esthetics (Poland), which is the head organization for the assignment "Determination of Anthropometric Data in Application to the Tasks of Machine Design," presented information on progress in research on applied anthropology. The coexecutors of this project are Bulgaria (Bulgarian Academy of Sciences Institute of Morphology), the USSR (VNIITE), and Czechoslovakia ((Karlov) University, Bratislava University imeni Ya. A. Komenskiy, and the Institute of Industrial Design). Anthropometric atlases for the populations of Bulgaria, Poland, and the USSR were compiled during work on the assignment. The material in the atlases was collected in accordance with a single procedure. Preparations are being made for publication of "Metodika antropometricheskikh issledovaniy primenitel'no k zadacham ergonomiki i dizayna" (The Methods of Anthropometric Research in Application to the Tasks of Ergonomics and Design), which will contain the methods for studying static and dynamic anthropometry (the scope of movements at articulations, zones of accessibility, the principles for developing human biomechanical models, and so on). Poland has approved a standard on anthropometric data.

The plan for the council's work for 1977 was approved at its third meeting. The next meeting, the fourth, will be held in September 1977 in Warsaw (Poland).

The meeting of the scientific-technical council was followed by the second meeting of the Council of Authorized Representatives on Problem I-37 "Development of the Scientific Grounds for Ergonomic Norms and Requirements." The meeting was attended by Bulgarian, Hungarian, East German, Polish, Romanian, Soviet, and Czechoslovakian representatives to the council of authorized representatives and persons accompanying them, by the director and colleagues of the Coordinating Center, by a colleague of the CEMA Secretariat, and by a colleague of the Administration for Scientific-Technical Cooperation With Socialist Countries of the USSR Council of Ministers State Committee for Science and Technology. The meeting was chaired by Comrade T. Balog, deputy director of the Hungarian Ministry of Labor Institute of Labor Research.

Information was given on decisions of the 13th Session of the CEMA Committee for Scientific-Technical Cooperation, in which special attention was focused on the suitability of distinct determination of the mutual responsibilities of the parties, the goals, stages, and conditions of the work, the technical-economic parameters of the expected results, the conditions for mutual exchange of information on these results, and the measures for utilizing them.

A working group for cooperation in scientific-technical forecasting was established as a working agency of the CEMA Committee; it will develop proposals pertaining to the basic directions, content, and forms of predictions of the development of science and technology. Academician V. M.

Glushkov, director of the USSR Academy of Sciences Institute of Cybernetics, was appointed chairman of the working group for 1976-1977.

Establishment of the International System of Scientific and Technical Information (MSNTI), which will be organized on the basis of the cooperation of national systems and creation of international information subsystems for national economic sectors and specific types of information, as well as on the basis of the activity of the International Center for Scientific and Technical Information (MTsNTI), which coordinates the work and scientific research pertaining to creation and development of the MSNTI, was announced at the 13th Session of the CEMA Committee. Seven specialized information subsystems and services have been created within the framework of the MSNTI thus far:

- On scientific research projects (reports, dissertations);
- on published documents;
- on industrial catalogues;
- on patents;
- on scientific and technical translations;
- on scientific-technical motion pictures;
- on registration of periodical publications of the CEMA countries.

Unified rates were developed and approved for mutual information services rendered in the MSNTI.

In accordance with decisions of the 13th Session of the CEMA Committee the council of authorized representatives has decided, with the goal of heightening the effectiveness of scientific-technical cooperation on the ergonomic norms and requirements problem and accelerating introduction of the obtained results into production, to develop proposals on completing the work on individual assignments and subassignments with preparation of draft standards and other technical standards documents, following in this case the statutes contained within the Convention on Application of CEMA Standards. In addition the issue of possible inclusion of production enterprises and associations into the working plans as clients and coexecutors of the project is to be examined.

A report on the basic directions of work in standardization of ergonomic norms and requirements and on the technical standards documents to be developed on priority was given by Comrade V. M. Munipov, the Soviet representative to the council of authorized representatives.

The council of authorized representatives approved the basic directions of the work of writing standards in ergonomics.

A decision was made to include topics and assignments pertaining to preparation of standards documents in ergonomics in the program for scientific-technical cooperation on the norms and requirements problem. These subjects and assignments are to take account of the work that has already been done by the countries. A decision was also made to decrease the subject matter of scientific research and postpone some of the projects until a later date so as to achieve concentration of efforts on the basic problems of developing the scientific grounds for ergonomic norms and requirements, and in order to accelerate preparation of standards documents.

Working plans on all subjects of the program for scientific-technical cooperation were approved at the meeting of the council of authorized representatives. Eighteen working programs were approved for six subjects in the program for cooperation:

"Development of the Theoretical and Methodological Grounds of Ergonomics" (USSR); "Development of Ergonomic Criteria for Optimizing 'Man--Implement of Labor--Production Environment' Systems" (Czechoslovakia); "Development of the Scientific Grounds for Ergonomic Assessment of the Quality of Industrial Products and Standardization of Ergonomic Norms and Requirements" (USSR); "Development of Ergonomic Requirements on Technical Resources Used to Display Information to a Human Operator" (USSR); "Development of a Single Complex of Methods and Apparatus for Ergonomic Research in Laboratory and Production Conditions, Including With the Use of Computers, and Unification of the List of Ergonomic Indices" (USSR); "Ergonomic Conditions for Technical Activity in the Planning and Operation of Complex Systems" (Romania).

In addition information was given at the meeting on the work of the Coordinating Center, and its work plan for 1977 was approved. The next meeting, the third, of the council of authorized representatives is planned for October 1977 in Dresden (GDR).

Report by L. I. Koncha, VNIITE

The first scientific coordination conference on Subject II "Development of Ergonomic Criteria for Optimizing 'Man-Implement of Labor-Production Environment' Systems" was held in March 1977 in Prague (Czechoslovakia).

Representatives from Bulgaria, Hungary, the GDR, Poland, the USSR, and Czechoslovakia took part in the work of the conference.

Subject II is central to Problem I-37 "Development of the Scientific Grounds for Ergonomic Norms and Requirements" as a whole, since determination of the economic criteria for optimizing "man--machine--production environment" systems is one of the most important problems of ergonomics as a scientific discipline.

The need for developing a unified theoretical conception and unifying, on its basis, all of the principal research on the subject's nine assignments was emphasized at the conference. The conference participants approved the basic theoretical premises on developing ergonomic criteria contained within a report by Comrade V. M. Munipov, director of the Coordinating Center, and they agreed that maximum coordination was needed in the methods, approaches, and objects of research pertaining to the assignments of the subject, that these subjects had to be tied in with other subjects in the problem, chiefly with Subject V "Development of a Single Complex of Methods and Apparatus for Ergonomic Research in Laboratory and Production Conditions, Including With the Use of Computers, and Unification of the List of Ergonomic Indices."

Comrade A. Zeleny, a representative of the head organization on the subject (Institute of Hygiene and Epidemiology, Prague, Czechoslovakia), informed the participants on the progress in work on assignments of the subject, pointing out that a certain amount of work had been done in satisfaction of the approved work plans, and that practical results had already been obtained in six subassignments.

The conference participants recognized the need for establishing close business ties between the Coordinating Center for the problem and the CEMA Permanent Commission on Cooperation in Public Health (in relation to the integrated problem "Labor Hygiene and Occupational Diseases"), since the plans of their scientific-technical cooperation mutually supplement one another.

Section meetings were held on individual assignments of the subject in accordance with the agenda:

- II. 1. Development of Hygienic Criteria.
- II. 2. Determination of Anthropometric Data in Application to the Tasks of Machine Design.
- III. [sic] 3. Development of Physiological and Psychophysiological Criteria.
- III. [sic] 4. Development of Psychological Criteria.
- II. 5. Solution of Some Psychosocial and Sociological Problems in Optimizing "Man--Machine--Production Environment" Systems.
- II. 6. Development of the Criteria of Engineering Esthetics.
- II. 7. Development of Integral Criteria.
- II. 8. Analysis of the Necessary Motor Activity of a Human Operator in the Conditions of Hypokinesia and Hypodynamia.

Corrections were made in the work plans, specific formats for the final reports for the projects were determined, methodological and theoretical problems pertaining to the indicated subjects were discussed, and reports on concluded projects were heard.

The conference participants made note that the Scientific Research Institute of Labor (USSR, Moscow) had published the work "Integral'naya otsenka rabotosposobnosti pri umstvennom i fizicheskom trude" (Integral Assessment of Efficiency in Mental and Physical Labor), which reflects the results of work on physiological criteria.

The results of work on psychological criteria were published in the book "Psikhometrika utomleniya" (The Psychometrics of Tiring) (Izd-vo MGU, 1977).

Participants of work on the criteria of engineering esthetics (VNIITE) published their results in the VNIITE publication TEKHNICHESKAYA ESTETIKA, No 10-11.

Taking account of the importance of substantial work on the assignment "Development of Integral Criteria," the conference felt it possible to have several approaches to research in this assignment, and to test these approaches out in the first stage of the work.

The conference and its results were given a high evaluation by the Czechoslovakian deputy minister for public health, who made special note of the atmosphere of friendship and business-like cooperation in ergonomics among specialists of the socialist countries.

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## ERGONOMICS

### DEFINITIONS OF TERMS, OBJECTIVES OF ERGONOMICS

Moscow TEKHNICHESKAYA ESTETIKA in Russian No 6, 1977 pp 1-4

[Article by USSR Academy of Pedagogical Sciences Corresponding Member, Dr Psych Sci V. P. Zinchenko, and Cand Psych Sci V. M. Munipov, All-Union Scientific Research Institute for Esthetic Styling in Engineering]

[Text] The continually growing amount of ergonomic data being acquired, expansion of the sphere of their application, inclusion of more and more new specialists in work on ergonomic problems, intensive training, improvements in training programs, and the rise in the qualifications of specialists in this area are continually forcing us to review the basic concepts of this science and its theoretical grounds. Indicative in this respect is the fact that in 1974, during the Tenth Congress of the Ergonomic Society of French-Speaking Countries, the subject of one of the plenary sessions was worded as follows by Prof B. Metz, former president of the International Ergonomic Association: "Does ergonomics need a new definition?" A group of experts consisting of specialists from different countries was formed at the international symposium "Application of Ergonomics in Industry, Agriculture, and Forestry" (Bucharest, 1974) to write definitions of the objectives of ergonomics.

Much was done during preparations for and conduct of the Sixth Congress of the International Ergonomic Association (Washington, 1976) to promote an examination of the deeper grounds of professional ergonomic activity by focusing attention on methodological and theoretical problems. At the same time, an analysis of the congress' proceedings would permit the assertion that the highly critical assessment of the state of ergonomics' theoretical foundation, made by the prominent American scientist D. Meister in a book which was published on the eve of the congress, remains valid in many ways today: "Human factors analysis is not relying upon any sort of fundamental, clearly developed conceptions of the 'man-machine' system."\*

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\*Meister, D., "Behavioral Foundations of System Development," New York, Wiley, 1976.

Specialists have recently been answering various sorts of questionnaires with the purpose of making the definition of ergonomics and its objectives more definite. The results of one such questionnaire, filled out by members of the Ergonomic Society of French-Speaking Countries, were reflected in Faverge's article "Ergonomics Through the Eyes of Ergonomists."\* This article contains interesting material, but its content simply reiterates the conviction that the subject of ergonomics and its objectives could be defined only on the basis of special theoretical and methodological research.

The theoretical and methodological problems of ergonomics are being worked on rather intensively in connection with implementation of the extensive, substantial program of scientific-technical cooperation among CEMA countries on the problem "Development of the Scientific Fundamentals of Ergonomic Norms and Requirements." This article summarizes the results of a certain cycle of research aimed at defining the subject of ergonomics (1-6) and systematizing the existing concepts pertaining to this issue in a certain way.

Ergonomics is one of the directions of the systems approach to studying man at work. The problematic orientation of modern science engendered ergonomics, the development of which is associated with the "man-machine" problem.

Ergonomics is a scientific discipline studying man (a group of people) in concrete conditions of his (or their) activity.

Man, machine, and environment are interpreted in ergonomics as a complex functional whole, in which man has the dominant role.

Interest in the "man-machine" problem arose in the mid-20th century. Various sorts of systems (production, transportation, communication, space flight, and other control systems), the functional effectiveness of which depends in many ways on the activity of an individual included within them, began to be the object of technical planning and design more and more often. A "man-machine" system consists of a human operator (or a group of operators) and a machine through which he (they) do work associated with production of material valuables, control, information processing, and so on. "Man as a component of a 'man-machine' system" is not an abstract being; he is a social individual included within a highly complex network of social relationships, which in the end defines the nature of his interaction with the machine. The role of the individual is not reduced here to just purely physical manipulation of controls depending on instrument readings or other signals from the machine. This manipulation acquires a social coloration (8).

We significantly increase the effectiveness of control by making human capabilities compatible with the capabilities of the machine (or a set of technical resources). Despite the fact that man and machine perform control

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\*Faverge, I. M., "L'ergonomie vue par les ergonomes," LE TRAVAIL HUMAIN, Vol 39, No 2, 1976, pp 299-310.

functions jointly, each of the two components of the system adheres to its own laws in its work. The effectiveness of the system's function as a whole depends on the extent to which features inherent to man and machine were revealed and accounted for in its creation, to include limitations and potentials. The main difficulty in analyzing "man-machine" systems lies in the need for uniting research pertaining to different areas using different analysis methods and different terminology into a single complex.

Having as its main object analysis of "man-machine" systems, ergonomics studies certain properties of these components having the closest relationship to the effectiveness of such systems; these are called human factors. This term, which came to being at the dawn of ergonomics and engineering psychology, has acquired a new interpretation as a result of recent theoretical and methodological studies. Human factors are integral characteristics of the association between man and machine, manifesting themselves in the concrete conditions of their interaction within a functioning "man-machine" system intended for specific objectives.

Hence it follows that human factors cannot be reduced to characteristics of man, machine, and environment taken alone. Naturally when we isolate such factors we make use of our fundamental knowledge of each of the components of the system, knowledge that is present and acquired in the appropriate sciences. The characteristics and properties referred to as human factors are not isolated qualities of the components of a "man-machine" system; instead, they are its aggregate, systemic qualities. "A new quality arising as the product of integration, of combination of many elements into a single whole, is something greater than the sum of the parts; it reflects certain general cooperative properties of the given set of phenomena, and it represents a supraindividual construct. And if we fail to distinguish such systemic qualitative constructs, we involuntarily reduce our efforts to subjective fetishism, attempting to find in the most concrete phenomena something which is outside of them, something that is an independent ('group' and not individual) reality" (9).

In relation to the properties and qualities of the components of a "man-machine" system, human factors are second-order qualities arising as a result of integrating, of combining, into a single whole, natural qualities characterizing the environment, objective qualities characterizing the machine, and functional qualities, including social qualities characterizing the individual. "The specific features of modern production elicit a need for studying not just the physicochemical properties of the implements of labor, for studying the qualities of materials, and for solving problems having to do with energy, but also entirely new problems within the competency of social sciences. The subject of scientific research pertaining to work becomes not the equipment by itself and not just the individual as a subject of production, but rather the coordination of the individual's physical and mental capabilities, esthetic tastes, and other social qualities with the properties of modern technical systems" (7).

Ergonomics is interested not in all possible "primary" qualities of man, machine, and environment, but only in those dependent on the place and role of man in the system (this is precisely why they are called human factors). This does not mean that they are small in number. It is apparent that sophistication and effectiveness would be highest in systems within which the number of human properties and qualities placed in functional association with the individual's place in the system, with its natural and objective qualities, is maximum; this is why individual sciences studying work (hygiene, physiology, labor psychology, engineering psychology, and others) cannot insure the effectiveness of a "man-machine" system by working alone.

Ergonomics must define a necessary and sufficient list of functional associations between elements in the "man-machine" system, inasmuch as only in this case would it be able to acquire the status of a system having a given effectiveness and satisfying certain criteria. The list of functional associations must be constructive and not infinite, and it must satisfy a large number of criteria by which the "man-machine" system is evaluated, both technical (stability, reliability, resistance to interference) and socioeconomic criteria. This is expressed concretely in the fact that ergonomics does not simply operate with various systems of initial properties, qualities, and indices (hygienic, physiological, psychological, psychosocial, technical, ecological, and so on) derived in the appropriate sciences; instead, it transforms them into systemic qualities, establishing the necessary number of functional associations between them.

Human factors interpreted as the most important integral characteristics of a "man-machine" system are thus a certain superimposition of initial indices and, correspondingly, fixed (or dynamic) functional associations between components in the "man-machine" system. Inasmuch as a "man-machine" system is a certain functional structure, from an ergonomic standpoint human factors are elements or taxonomic units of analysis of the functional structure of the system. Naturally, the functional structure of a "man-machine" system is distinguished not only by human but also other factors--organizational, informational, territorial, and so on. Human factors pertain to that property of a "man-machine" system which some authors call "ergonomicness." Therefore isolation of human factors as taxonomic units of analysis--that is, as elements of the system's infrastructure, naturally does not preclude isolation of taxonomic units of other sorts depending on the objectives of analyzing such systems.

Human factors are not homogeneous. Their isolation and classification is a rather complex and special task. It would be important to note that human factors are structural constructs of different degrees of complexity. Defined in this way, they are a certain temporary combination of strengths capable of achieving a certain goal.

Continuing this analogy, it would be pertinent to introduce the concept of symptom complex, broadly employed in medicine and physiology, into the

context of the theory and practice of ergonomics. We define an ergonomic symptom complex as a certain combination of human factors which are dependent on the functional structure of the concrete activity of an individual in "man-machine" systems of a particular type, and which in turn insure optimum operation of these systems with an eye on achieving particular objectives. It is important to isolate the dominant system-forming factors having a decisive influence upon human activity from the ergonomic symptom complex, which includes a certain set of human factors.

This definition of ergonomics and human factors steers us clear of the widespread viewpoint that ergonomics is some sort of metascience, integrating other sciences within itself. The status of ergonomics is defined by the fact that it makes use of data acquired by other sciences and transforms them, developing its own initial ideas and resources, and pursuing its own goals and objectives associated with organizing and planning the conditions and methods of human work in a system.

Human activity is precisely the grounds for isolating the human factors that must be accounted for, the human factors to be used in defining the functional associations between components and defining the "man-machine" system itself. It is just as valid to say that presence of such functional associations provides the necessary foundation for organizing human activity in a system and insuring its successful conduct. "Systems of this sort are in a class of so-called purposeful systems. In such a system, man sets the goals, defines the tasks, and selects the methods for completing them. The purposeful activity of the human operator must become the starting point for analysis of the 'man-machine' system" (10).

Human factors are the unknown, that which can be found only through preliminary analysis of the tasks of the "man-machine" system, the functions of the individual within the system, and the type and nature of his work.

Such an analysis is a necessary prerequisite for the planning of "man-machine" systems. The fact that such analysis can be conducted with a greater or lesser degree of professionalism, at an intuitive or a scientific level, empirically, or experimentally (using the appropriate prototypes, mock-ups, experimental testing units, or real devices) is another matter. As a result of such preliminary analysis of the activity we define the list of human factors which must be accounted for if the "man-machine" system is to function effectively. The completeness with which the human factors and the wealth of potential functional associations between components of the "man-machine" system are isolated in the system's planning stage has a significant effect on the ease with which such systems are introduced, to include the ease of formulating the requirements on occupational selection and personnel training, and coordination of external work resources and the internal methods by which the work is done, and so on. A correctly isolated and structured system of human factors manifests itself in successful operation of the "man-machine" system, in fulfillment of the tasks ascribed to it. Applied problems of ergonomics are solved in application to a particular type of "man-machine" system, in application to a particular form of operator activity.

Thus human activity is the start and end of ergonomic research, ergonomic assessment, and ergonomic planning. The activity concept is also the theoretical foundation for the interpretation of human factors presented above. Thus new conceptual schemes of activity and new methods of its analysis take shape in ergonomics, stimulating development of a general theory of work. This theory leaves room for specification and assessment of the true role of the implements of labor (the technical resources) which intensify and transform human functions and capabilities--that is, objects representing the external resources of work. In this respect the problems of ergonomics intersect with praxis, which has the objective of studying the general laws governing any sort of activity and defining, on this basis, the most general rules for organizing activity. Using the Marxist teaching on objective activity, its development, and its forms as its basis, ergonomic research has made a productive inroad into the sphere of the theory and methodology of work.

Ergonomic problems can be solved effectively only on the condition "that synthesis of social and natural sciences is directed not into the path of mechanical combination of the data of certain sciences or others into a certain summed system or a conglomerate of knowledge, and not into the path of their 'cosubordination,' but rather into a path based on a general theory of work" (7).

Ergonomics studies problems associated with the objectives of sensibly organizing the activity of people in "man-machine" systems and purposefully distributing functions between man and machine, operation of these systems, determination of the criteria by which to optimize them with a consideration for the capabilities and specific features of the individual (group of individuals), and development of a classification of such systems. Other problems that can be called ergonomic include those of defining the methods by which to assess the dynamics behind the functional state of a working individual, and revealing the optimum characteristics of the "man-machine" system's environment. A large number of ergonomic problems are associated with the task of planning workplaces and working conditions for people of lower efficiency. A unique class of problems arises in connection with determining the object of standardization in ergonomics.

Ergonomics is simultaneously a scientific and a planning discipline, since its objective includes development of the methods by which to account for human factors when modernizing existing equipment and creating new equipment and processes. "Ergonomics," states the booklet "Ergonomics" published by the Loughborough University of Technology (England), more precisely by the department of human sciences chaired by the prominent English scientist (B. Shekkell), "is simultaneously a science and a technology. It makes use of the methods of human science to study interaction between man and his occupational activity, his equipment, and his environment; it makes use of knowledge from different human sciences to solve practical problems arising through this interaction" (11).

This feature is inherent not only to ergonomics alone. A trend called technologization of the social sciences has recently taken shape; works examining the problems of Marxist social technology have appeared. "If the social sciences," writes the Bulgarian scientist N. Stefanov, "really want to not only explain but also change the world, they must also develop as technological knowledge" (12).

Ergonomics plans suitable variants of concrete forms of human activity associated with using new technology. Requirements imposed on equipment used in work and, simultaneously, requirements on the methods of occupational selection and the technical training resources are formed on the basis of the activity plan written in correspondence with the basic objectives of the "man-machine" system being created. "We must apparently begin to think about another direction today: We must base development of a technical assignment on the idea of the secondary, servicing function of machines, and consequently we must first of all account for the positive qualities of the individual as the real subject of labor--that is, not his shortcomings but rather his advantages in comparison with the machine. By doing so we reveal fundamentally new reserves for heightening the effectiveness of labor--that is, reaching one of the most important objectives of the Tenth Five-Year Plan. In the future we can switch from solving the unpostponable problems of labor organization, improving the existing equipment, and adapting man to the technological norms already present to the planning of new forms of human activity based on integrated theoretical analysis of human potentials, which is the subject of ergonomics today" (7).

During such planning, not only do the external resources govern the internal methods of activity; in correspondence with the latter, the external resources are also "transformed," as a result of which conditions promoting adequate manifestation of the labor of the individual (a group of people) are made optimum. Under socialism, ergonomics promotes creation of conditions, implements, and work processes which permit us to achieve a three-fold objective more effectively--heightening labor productivity, preserving human health, and developing the personality fully.

The objective area of planning in ergonomics is expanding owing to the inclusion of various objects making up the objective-spatial environment of human vital activities. Today, one of the most important spheres of application of the results of ergonomic analysis is the planning of consumer goods, especially cultural and personal articles. Working in close cooperation with industrial design, ergonomics must insure that the articles have good consumer properties, that their appearance is beautiful, and that operating convenience is improved. "We need hardly mention the fact," A. Chapanis notes, "that ergonomic problems associated with consumer goods are in a certain sense problems of the ergonomics to which we have been accustomed. It is not the ergonomics of labor, not the ergonomics of enterprises and systems, and not the ergonomics of production processes. It is ergonomics affecting everyone, young and old, because all of the problems have to do with commonly used articles surrounding everyone. It is ergonomics of an

entirely different sort, but it is nevertheless ergonomics. This is the ergonomics we have yet to study" (13).

The systems approach provides the methodological basis for ergonomics. It permits use, in ergonomics in one combination or another, of methods from different sciences at the borders of which qualitatively new problems in "man-machine" system analysis arise and are solved. In this case the methods employed undergo certain transformation, to a point where new methods are created. Ergonomics makes use of analysis methods which have evolved in sociology, psychology, labor physiology and hygiene, functional anatomy, cybernetics, systems technology, and other sciences. The problem is to coordinate the different methods to solve one ergonomic problem or another and subsequently generalize and synthesize the results obtained by these methods.

The methods of structural systems analysis of activity, including the special methods of functional-structural and microstructural analysis, have important significance to ergonomics. Development of these methods and their use in applied and experimental ergonomic research have led to arising of entirely new problems pertaining to the criteria by which to assess work effectiveness. Specialists involved in assessing and planning "man-machine" systems have used external, derived, general systems criteria to assess the effectiveness of operator activity, such as speed and accuracy, for many years. Use of the new methods for analyzing activity has made it possible to begin development of activity assessment criteria inherent to the activity itself and reflecting its significant features.

The need for employing mathematical methods is acutely felt in ergonomics. Mathematical models of human factors have recently been appearing in greater quantity in engineering. Of course far from all of them are real models of human factors: Modeling is often transformed into a game with mathematical symbols representing nothing real. But despite this, the desire to mathematically describe human factors doubtlessly promotes development of ergonomic theory in general.

Ergonomics relies upon the entire complex of sciences having as their object of research man as a subject of labor, cognition, and communication. It synthesizes the achievements of psychology, labor physiology and hygiene, engineering psychology, functional anatomy, and a number of the technical sciences. Ergonomics is developing in close interaction with the sociology and economics of labor, cybernetics, systems engineering, operations analysis, industrial design, and scientific organization and protection of labor.

The problems of ergonomics are being worked on by collectives of specialists including, depending on the concrete nature of the problems requiring solution, certain combinations of psychologists, physiologists, hygienicists, anthropologists, sociologists, economists, mathematicians, designers, architects, and engineers. According to A. Chapanis' definition, ergonomics is a "multidisciplinary area of knowledge. It is at the boundary of many

sciences and professional disciplines, and it gleans data, information, and principles from all of these disciplines. Ergonomics is an alloy of psychology, physiology, medicine, anatomy, toxicology, and research on the problems of control and engineering. Were we to recall this essence of the nature of our profession, it would become easier for us to understand why this science varies in its final expression from country to country and even within the same country. I would like to say that only the statistics of the fluctuations compared could explain the differences in the proportions of the different scientific disciplines which we can find in all of our organizations" (14).

As they undergo formation, the conceptual machinery and analysis methods of ergonomics are having a continually growing influence on the development of the sciences at the boundaries of which ergonomics arose. An analysis would show that the systems approach to studying man in the concrete conditions of his activity in modern production will dominate in the next few years over the entire course of scientific and applied progress in this area. "Development of integrated research should gradually lead to reorganization of the entire system of sciences contributing to this research" (15).

An attempt at analyzing the specific features of labor quality concepts has been made on the basis of the conception of the object and objectives of ergonomics examined here. Defining these concepts, economists distinguish such characteristics as complexity (qualifications), intensity, difficulty, conditions, and national economic significance. These characteristics are being accounted for in wage standards.

The characteristics of labor quality concepts associated with social effectiveness are not fully revealed with this approach. As an example V. G. Afanas'yev examines this problem in application to the planning and creation of automatic control systems as follows: "Automatic control systems that are outfitted well from a technical standpoint, that work according to a distinct program, and that enjoy fabulous informational and mathematical support play a major role in developing and educating the personnel, the only component that can insure the effectiveness of the system's operation. And not only from an economic standpoint. Inasmuch as this type, this nature of automatic control system shapes the individual as a highly qualified specialist and an erudite person who thinks creatively, it is also socially effective, in the sense that it stimulates growth in the cultural and technical level of the personnel, their initiative, and their creative activity, and thus promotes full development of the individual--the goals, resources, and ideals of the society of the future" (16).

Creation of conditions favoring full development of the capabilities and creativity of Soviet people and of all laborers in the period of communist construction is becoming an urgent need of our country's economic development itself. One of the most important directions for reaching this objective is to improve working conditions, improve the nature and enrich the content of labor so that it would become not only more productive but also

more interesting and creative. We believe in this connection that examining the "labor quality" concept only from the standpoint of economic science is not enough to fully reflect the specific features of this concept in the conditions of developed socialism.

Quality is an integral characteristic of a given form of labor embodying indices of the quality and quantity of the product in relation to the labor outlays, the psychological and physiological "price" of the activity, and in relation to indices describing the health and development of the worker's personality. The mutual associations and mutual dependence of all of the listed components result in an integral system of the quality of the given form of labor, a system of many levels. Definition of labor quality indices presupposes comparison of the acquired data on individual components with knowledge of the quality of the particular form of labor viewed as an integral system. The task of studying labor quality as a whole is acquiring priority today; by studying it in this way, we can gain a deeper understanding of its components and the relationships between them. The problems of labor quality require integrated research by the methods of different sciences, among which ergonomics is called upon to make a certain contribution.

High labor quality has important significance to reaching the diverse economic and social objectives posed to the Soviet people by the 25th CPSU Congress. High labor quality not only promotes high qualitative and quantitative indices for products at least labor outlays and at the lowest psychological and physiological "price" of activity, but it also promotes maintenance of health and development of the worker's personality to the maximum. "The most sensible (in relation to each specific stage of scientific-technical progress) provision of equipment to man and maximum satisfaction of his need for creativity in labor" (7) should be the main criteria of optimum interaction between man and machine.

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## ERGONOMICS

### NEW STANDARDS ON OPERATOR SWITCHES

Moscow STANDART. EKSPRESS-INFORMATSIYA in Russian No 38, 1977 pp 16-17

[Excerpt from "Standart. Ekspress-Informatsiya" (Standard. Express Information Service), All-Union Scientific Research Institute of Technical Information, Classification, and Coding, USSR Council of Ministers State Committee for Standards, Izdatel'stvo Standartov, 9,130 copies, 24 pages]

[Text] GOST 22614-77. "Man-Machine" System. Key and Push-Button Switches and Selector Switches. General Ergonomic Requirements

This standard has been written for the first time. It was approved by a resolution of the USSR Gosstandart [State Committee for Standards] dated 4 July 1977; it is effective as of 1 July 1978.

The goal of writing this standard was to systematize ergonomic requirements on the shape, dimensions, and mutual arrangement of key and push-button selector switches and switches on the control panels of objects classified as "man-machine" systems. Compliance with these requirements will insure the greatest working convenience, reduce the tiring an operator experiences, and decrease the probability of operator error, resulting in greater labor productivity and higher effectiveness in use of the equipment.

The standard establishes general ergonomic requirements on key and push-button switches and selector switches in "man-machine" systems.

Introduction of the standard will improve the design characteristics of switches and selector switches, and it will heighten their esthetic level and the convenience of their use, which in the end will promote creation of optimum conditions for operator activity.

GOST 22615-77. "Man-Machine" System. Tumbler Switches and Selector Switches. General Ergonomic Requirements

This standard has been written for the first time; it was approved by a resolution of the USSR Gosstandart dated 4 July 1977; it is effective as of 1 July 1978.

The goal of writing the standard was to establish general ergonomic requirements on tumbler switches and selector switches in "man-machine" systems.

The standard establishes general ergonomic requirements on the dimensions and shapes of article actuating components, on the mutual arrangement of switches mounted on control panels, and so on.

Introduction of the standard will improve the design characteristics of switches and selector switches and heighten their esthetic level, which will promote creation of optimum conditions for operator activity.

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## ERGONOMICS

### BOOK ON ERGATIC SYSTEMS THEORY PUBLISHED

Moscow TEKHNIЧЕСКАЯ ЭСТЕТИКА in Russian No 4-5, 1977 p 54

[Review by Dr Psych Sci V. F. Venda, USSR Academy of Sciences (IP), of the book "Nachala teorii ergaticheskikh sistem" (Principles of the Theory of Ergatic Systems), Kiev, Izd-vo Naukova Dumka, 1975]

[Text] Izdatel'stvo Naukova Dumka published the monograph "Nachala teorii ergaticheskikh sistem" by Prof V. V. Pavlov in 1975. This book develops and presents the mathematical theory of the functional structure of "man-machine" systems (or ergatic systems).

The importance of research in this direction is obvious, and it is practically justified, inasmuch as the mathematical methods of ergonomics permit us to design and create man-machine systems of previously set quality. By using these methods we decrease the outlays of time and materials, since creation of man-machine systems usually involves building natural mock-ups, models, and experimental models of complex systems.

In his monograph Prof V. V. Pavlov proves the basic premise that the theory of the structure of man-machine complexes must be based on the systems approach, which combines the fundamental methods of the theory of technical system control and the theory of living organisms into a single whole. In the author's opinion, under such conditions we can "use the results of the many centuries of evolution of living organisms and man as the objective basis for creating sophisticated ergatic systems." First the author formulates and analyzes the general principles of living organisms, which reflect the result of the action of the evolutionary mechanism, and then he describes them in formal mathematical terms as a reflection of profound objective laws behind the structure of ergatic systems; finally he develops and uses the mathematical methods of control theory in order to embody certain objective laws in the form of the structures of man-machine systems.

The following principles of living organisms are introduced into the mathematical theory of man-machine system synthesis: Activity, functional homeostasis, technological homeostasis, independence, stability, least interaction, and efficiency. He borrows from control theory the principles of invariance,

independence, controllability, optimum, and normalization; in addition he introduces the coordinating principle of integral and functional compatibility between man and the functional structure of the system being created.

I believe that this set of principles can serve as an adequately complete system of initial axioms for initiation of the development of a formal theory of "man-machine" systems.

Let us examine three important principles interpreted in an original way by the author: 1) Technological homeostasis; 2) efficiency; 3) compatibility.

The author transforms the principal of homeostasis in its conventional interpretation, under which a certain set of significant variable parameters of the body must be maintained within assigned limits, into the principle of technological homeostasis, according to which the conditions and resources of normal technological function of the body itself must be provided. V. V. Pavlov believes that despite all of the importance of this principle, it cannot serve as the basis for synthesizing the structure of a man-machine system having the property of behavioral activity. This is what led to the need for developing the so-called principle of functional homeostasis, which declares that a living organism has the capability for maintaining stability in a certain set of its functional behavioral acts.

When worded in this way, the activity principle no longer contradicts the homeostasis principle, which had formerly created certain obstacles on the road to developing a full set of axioms pertaining to a complex biotechnical organism in all spheres of a "man-machine" system's functions. Here perhaps lies the general theoretical significance of the principle of functional homeostasis, which reaches beyond the theory of ergatic systems.

The author defined the principle of efficiency concretely, with a consideration for the activity principle, as a method for choosing that system out of a certain set of systems which would have, in the space of states (under otherwise equal conditions), the largest domain of possible manifestations of functional homeostasis in relation to its active functional behavior. This interpretation of the efficiency principle also has independent theoretical significance.

Examining the compatibility principle, the monograph's author suggests solving the problem of compatibility between man and the technical part of a system on the basis of a concept he introduces, the generalized working characteristic (ORKh) of the human operator as a unit in a closed system.

The ORKh concept itself permits us to formalize the concept of operator activity with the assistance of a functional dependence describing the length of time man can remain in a quasistable state as a function of parameters describing the complexity and dynamism of information presented to the individual by a display, and the content of operations the individual performs with the given information. All ORKh parameters are presented

as general systemic values, permitting solution of the compatibility problem and the problem of distributing functions between man and machine.

If we are to build a theory of ergatic system synthesis, it is very important for us to switch from verbal formulations of the sets of axioms pertaining to ergatic systems to their mathematical formulations; this affords a possibility for solving the problem of structuring man-machine systems using the formal methods of control theory and computers. Depending on the particular subset of axioms we select as the basis for synthesizing ergatic systems, we get man-machine systems of different types, classes, and so on. V. V. Pavlov distinguishes between the classes of ergamats (single-purpose systems), ergatic organisms, and superorganisms. All stages of structuring such systems are explained sufficiently thoroughly and strictly in the monograph. The author places his reliance on synthesis of ergatic systems functioning in an environment of acute conflicts. This is illustrated in the work with examples of a game-playing misinformed ergamat and a space ergatic organism.

While we derive the functional structures of all classes and types of systems by implementing the basic axioms of ergatic systems with the assistance of the methods of control theory, we make the structures more specific using the generalized work characteristic and the compatibility principle. As a result we define not only the structure of the system and the functions of the control system's technical parts and man, but we also define the necessary content of the information and the way control signals providing real instructions to the human operator are to be processed.

By applying systems theory to synthesis of complex man-machine systems we form ergatic organisms which not only have external and internal functionally homeostatic forms of control but also contain "conscious" and "unconscious" levels and spheres within a control system with a complex multidimensional symmetrical structural skeleton.

V. V. Pavlov's monograph "Nachala teorii ergaticheskikh sistem" is devoted to ergonomic problems lying at the boundary between technical and biological sciences. This is the first work pertaining to this direction, and therefore it does contain debatable concepts and premises. In his discussion of the ORKh, as an example, the author should have pointed out that it has thus far been tried out only in relation to very particular forms of operator activity. Moreover the author fails to show the methodological associations between optimization of operator activity specifically and selection of an efficient structure for multicomponent systems displaying information on ORKh form. Nor does the book analyze the language used in communication between man and machine. The author placed all of these problems within his indivisible "information display system--man--control device" block. On one hand this helps the author, inasmuch as it permitted him to examine this block using general systemic variables and, consequently, to solve the functional and structural problems, but on the other hand it excluded many specifically ergonomic and design problems pertaining namely to this block from the examination.

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## PSYCHOLOGY

### INVENTION PROBLEM SOLVING ALGORITHM

Novosibirsk EKONOMIKA I ORGANIZATSIYA PROMYSHLENNOGO PROIZVODSTVA in Russian  
No 3, 1977 pp 160-166

[Article by Cand Psych Sci N. P. Lin'kova, Senior Scientist, USSR Academy of Sciences Institute of Psychology, Moscow: "Imagination Within the Framework of the Goal"]

[Text] Each year the USSR State Committee for Inventions and Discoveries receives over 100,000 claims and issues about 40,000 inventor certificates.

Scientific organization of the creative process of invention is one of the most important ways for heightening production effectiveness. There are different methods for organizing the work of inventors, and different ways for activating their creative enquiry. There is an integral ARIZ (Algorithm for Solving Invention Problems) system in the USSR. The ARIZ is being taught in 40 of the country's cities. Nevertheless few engineering collective executives, or even creators of new equipment and inventors, know about it yet. But in the opinion of its creators, not using the ARIZ system in this century of scientific-technical revolution is about the same as excavating with a shovel without suspecting the existence of an excavator.

The experience of creating the theory of solving invention problems can doubtlessly be utilized when developing the theory of scientific creativity, the theory of management creativity, and so on. The ARIZ system may become the prelude to development of a general theory of creativity embracing various forms of activity.

We hope that acquaintance with the algorithm for solving invention problems will be useful to all of our readers, inasmuch as they are all involved in creative work.

The contradiction between the requirements imposed on a specialist and his real capabilities is becoming more and more acute. What we find in this case is that enterprise executives complain about poor specialist training, VUZ workers complain about the low level of school education, and teachers and parents complain that students are overloaded.

The most widespread method for overcoming this contradiction is to increase the number of executors, to accelerate the training of continually larger numbers of specialists. According to research data a doubling of the volume of scientific production in each decade would require a sixteen-fold increase in the number of scientists and more than a thirty-fold increase in allocations.\*

Clearly, this road is short: It can be traveled for only a short time. The whole world has begun seeking methods by which to intensify creative activity, engineering activity sooner than other types.

This search has been following two channels--an "irrational" one (brainstorms, synectics), and one relying on analysis of the logic behind the creative process. We should note that the latter channel has been found to be less "navigable"; it is found to be more difficult, though we can say that it is more scientific. The former, the "irrational" channel, is based on use of the subconscious, the uncomprehended, about which we know little as yet.

Methods aimed at acquiring new ideas on the basis of intuitive thinking arose out of the "brainstorm" conception.

Creating his "brainstorm method," A. Osborne (USA) based himself on the following premises. Criticism, or even just the anticipation of criticism, is a serious interference to creativity. Thus the main rule of the "brainstorm" is prohibition of any sort of criticism during the time ideas are generated. It is very difficult to comply with this rule. Osborne himself recognizes this, as do all who have used his method. After all what we are essentially referring to is conscious control of mental processes.

This method had many proponents at first. Osborne's book has been reprinted many times. He acquired many followers showing that use of the "brainstorm" could heighten the productivity of the thinking of the "brainstorm's" participants. Then interest in this method began to decline. Its main shortcoming is that it is based on utilization of circumstances. In the opinion of a number of researchers the effect of the "brainstorm" has one opposite to that for which the method was intended.

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\*Mangutov, I. S., "Inzhener" (The Engineer), Moscow, Izd-vo Sovetskaya Rossiya, 1973.

Of course attempts were made to somehow improve and reinforce the "brainstorm" method by transforming its participants into professionals making use of certain procedures. A special method--"synectics"--arose as a result (V. Gordon, USA). A group of synecticians used the method of free associations intensified by application of various sorts of analogies. But this method has essentially the same basis as the "brainstorm."

Chance associations are used in many methods. Typical among them is the "method of focal objects," recalling fishing in an unfamiliar place. We do not know where in the given water basin the fish is located (and if it is present, then what sort is it?); therefore we continually change our bait with the hope that the fish would bite at one of the baits. Chance words are the bait, and the "fish" is the new idea. Continuing the analogy with fishing we come to the following conclusion: If our main objective is to catch as many fish as possible, regardless of species, it would be best to use a net instead of a rod. In this case we could catch all of the fish. All we would have to do first is prepare the net.

All of these methods contain a serious contradiction. Their goal is to achieve the fullest grasp of the solution, to acquire the largest number of ideas. It is all based on the assumption that at least a few good ideas would necessarily be found among a large number of ideas. With this we can agree. But the difficulty of revealing the needed solution among "dead ends" grows correspondingly. When morphological analysis is employed, the number of ideas obtained reaches astronomical proportions; thus their analysis transforms into an insoluble problem. Of course, were there a possibility for clearly wording the criteria and for developing a procedure by which to assess the effectiveness of each variant, the number of variants would cease to be an interference: Their analysis could be entrusted to a computer.

Familiarization with these and similar stories would show that activation of technical creativity just by means of removing the psychological barriers cannot satisfy present needs. Thus it is no accident that a trend of growing visibility of somehow organizing the work, of subordinating the search for solution of a problem to a rational approach can be observed even among proponents of the irrational direction.

## 2

The latter direction for organizing technical creativity differs fundamentally from the former: It involves systematization of the search for a solution on the basis of analyzing the laws governing development of science and technology in general, and the laws governing development of the systems being planned in particular. The ARIZ system, proposed by G. S. Al'tshuller, can serve as a typical representative of this direction.

A student acquainting himself with the ARIZ system often gains a number of misunderstandings hindering his correct understanding of the system. Thus it would be a good idea to examine these misunderstandings specially.

The first group of misunderstandings involves inclusion of the word "algorithm" into the name of the method itself. It may appear to some that the concepts "creativity" and "algorithm" are incompatible. But what such persons fail to recognize is that the term "algorithm" is used with several meanings today. In the narrow sense, this word means an absolutely determined sequence of mathematical operations, while in the broad sense it means any program of actions of sufficient clarity. As the method's author himself points out, this is precisely the sense in which the ARIZ system is referred to as an algorithm.

The second group of misunderstandings is associated with the fact that many elements of the method appear to be well known. Thus the novelty of this form for organizing creative activity is brought to question.

We have long known that inventors make use of certain procedures in their work. Lists of procedures have even been compiled, which become longer and longer with every year. But as a rule these are simply lists. For the most part nothing is said about how and when a particular procedure should be used. Meanwhile, priority attention is placed precisely on this aspect of the issue in the ARIZ system.

Resolution of various technical contradictions has occupied a major place in the activity of the engineer. However, the way the procedures for resolving these contradictions are used depends on the extent to which they have been revealed and the causes behind their arising have been understood.

The method of analogy enjoys very broad use in science and technology. It has become an inherent component of both synectics and the ARIZ system. However, synectics simply points out the possible forms of analogies and suggests that we teach ourselves to search for them, placing our hopes on luck. In the ARIZ system, meanwhile, the use of analogies, as well as of all other methods, is included within the general system for seeking a solution.

Many debates and disagreements center upon the problem of the psychology of creativity. Apprehensions are stated that by organizing the creative process we will suppress inspiration, make capabilities unnecessary, and deprive the individual of the use of his intuition. Inventors themselves are the most active in defense of intuition and capabilities. In his article "How to Saddle the Technical Pegasus"\* T. Shilakadze, director of (Gruzdornis), glorifies inspiration, which is supposedly encroached upon by those who appeal for organization of the creative process. However, the article's concluding lines are somewhat of a surprise: "Every person involved in technical creativity willingly or unwillingly gathers together his own arsenal of resources. The more of such procedures there are, the more quickly and better the innovations are born, and the larger the number of

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\*TEKHNICA I NAUKA, No 5, 1976.

innovators that have mastered the procedures, the more effective is the technical process." But, after all, not only can we accumulate such procedures by ourselves, but we can also make use of those that have been accumulated by predecessors. And were we to acquaint ourselves with the way such methods are used, the work would become even more effective.

Technical creativity cannot be organized without studying psychological problems. When included into a particular system, all such problems (intuition, its place in the creative process and its mutual relationship with the logic of thinking, psychological barriers, the inertia of thinking, individual differences) produce new aspects and new possibilities in the methods. We can of course sit and wait for the onset of inspiration, or we could organize the work in such a way that it would elicit the necessary emotional atmosphere. This is how, in particular, many prominent artists, composers, actors, and writers have worked. Then why would this be impermissible in relation to technical creativity?

The ARIZ system also includes an entire complex of procedures directed at surmounting the psychological barrier. Such barriers may arise in response to the experience of predecessors and the sets generated by the way the problem is worded. The problem solver often modifies the problem, imposing additional conditions, though he himself might not recognize that he is doing so. Sometimes the cause of failure may lie in entirely insignificant interference, and the work would stagnate for a long period of time.

One of the central elements of the creative process is imaginative activity; therefore the method contains a number of procedures directed at activating it. We can cite as an example the RVS [dimensions, time, cost] procedure, which involves successive change of each of the system's characteristics from zero to infinity. (The name of this procedure came from three parameters--dimensions, time, cost). The main purpose of the procedure is to broaden the zone in which a solution is sought, to improve the problem solver's understanding of the problem's conditions, to activate his imagination, and to surmount the inertia of thinking.

Another procedure, which has come to be called "little people," has the purpose of developing the descriptive aspect of thinking. (The ordinary structure of a substance is represented as a system consisting of little people). This procedure is especially necessary when we must follow the modifications and interactions of very small particles, including those at the molecular level. Ordinary visuality and ordinary resources for representing the problem are found to be inadequate in this case, and for this reason we must resort to descriptive symbols, such as "little people."

The ARIZ system is itself a theory undergoing development. Here is what people offering instruction in the ARIZ system have to say about this.

"We are studying the technical literature, chiefly patent literature, and we are seeking and revealing the laws governing development of technical

systems. This permits us to continually introduce new 'mechanisms' into the ARIZ system. As an example we had known earlier that development of technical systems proceeds through resolution of technical contradictions. We were able to establish that each technical contradiction is based on a physical contradiction (the same part of an object may be in two different physical states--hot and cold for example--at the same time). Thus we introduced the procedure of revealing physical contradictions, and we immediately heightened the effectiveness of solutions acquired with the assistance of the ARIZ system.

"By processing large masses of patent (and other) information we have continually strengthened the information part of the ARIZ system (lists of procedures and the objects of their application, tables on use of physical effects, and so on).

"But what is more important is that the ARIZ system is experiencing evolution as a result of intensive use. After each lesson the instructor has 20-30 recorded problem solutions. Each such record is essentially an experiment data sheet. These records show the errors of the instructor (what precisely was incorrectly explained), errors of the student (what was incorrectly understood) and, mainly, errors of the ARIZ system itself (where and why was the method unable to lead the student to the correct solution, help him surmount psychological inertia, and give a clue as to the necessary procedure or the physical effect). Each instructor accumulates 500-1,000 such records in a school year. Multiply this by the number of instructors. Each year we analyze all of the material obtained, and we make corrections in the ARIZ system and in the instructor's procedures. Hence the rate of development is swift. We do not need expensive equipment; every new idea could be tested out in practice immediately. It is easy for us to create extremely pure experimental conditions: The same problem is sent to correspondence students in different cities (we enroll 20-30 correspondence students each year), and the instructor is unable to give any clues to the student, even involuntarily: It is entirely up to the ARIZ system. We compare the records, and we make conclusions as to the viability of the ideas."

The method's interaction with other sciences has had a great influence on its evolution. Thus use of the ARIZ system to solve physical problems has led to arising of a new direction in technical creativity--analysis of the way for using physical effects when solving technical problems (an index of physical effects has been compiled, tables for their use have been created, and special procedural handbooks have been published). The method for solving technical problems has promoted organization of research in the psychology of technical creativity.

Owing to all of this work the initial method, which was intended only for technical problems, began to gradually transform into a certain system by which to organize the creative process in engineering in correspondence with present requirements. The ARIZ system is the basis of this system,

but it cannot be reduced to just the ARIZ system alone. A natural transition has occurred from methods to the theory of solving invention problems. The next step is transition to the theory and methodology of organizing technical and scientific creativity, which are being found to be more closely associated with every year.

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## PUBLIC HEALTH

### EPIDEMIOLOGICAL ASPECTS OF POLLUTION OF THE ENVIRONMENT WITH CARCINOGENIC SUBSTANCES

Alma Ata ZDRAVOOKHRANENIYE KAZAKHSTANA in Russian No 5 (374), 1977 pp 68-69

/Article by B. A. Nemenko and M. M. Moldakulova, Kazakh Scientific Research Institute of Oncology and Radiology/

/Text/ The application of the term "epidemiology" to noninfectious diseases (hypertonia, atherosclerosis and malignant tumors) is encountered more and more often and includes problems connected with a comparative study of diseases widespread among the population of various countries. The concept of "epidemiology of environmental pollution" is used much less frequently, although it has been in existence for quite a long time. This definition applies to the problem of protecting the health of the population in connection with the pollution of atmospheric air, water, soil and industrial and domestic environment with various harmful substances.

The first conference devoted to the epidemiology of atmospheric air pollution was organized by the European Regional Office of the World Health Organization in Milan in 1957. Then the Geneva Conference of the Committee of Experts of the World Health Organization was held. The problem of improving the environment on a global scale was discussed at that conference. Owing to the growing universal interest in problems relative to the epidemiology of atmospheric pollution, the need for coordinating scientific research arose. For this purpose a symposium, in which representatives from 14 countries participated, was held in Copenhagen on 13-16 December 1960.

An increased incidence of cancer of individual localizations, especially lung cancer, among the population has been observed in many countries in the last few years. As long ago as 1897 A. Perutz wrote that lung cancer occurred only in isolated cases, whereas at present in its frequency this disease holds one of the first places in the structure of oncological diseases. Many authors connect this phenomenon with the increased pollution of the environment with carcinogenic substances. For example, according to the data by P. Stocks (1959), "... lung cancer occurs most frequently in London's northeastern part, where, in accordance with 'the wind rose,' atmospheric pollution is carried from the city's industrial areas." The author obtained similar results in a study of the urban, rural and mixed population of Wales and

Britain's northwestern regions. In this case environmental factors and the social conditions of patients suffering from lung cancer were compared with the same conditions of the control group of nononcological patients.

About 1,000 chemical compounds causing tumors in experiments on animals are now known. However, the number of substances significantly blastomogenic for man is not so large. Most of them are of industrial origin and have been studied in connection with the appearance of cases of occupational cancer in industry. They include asbestos, chrome, arsenic, nickel, their compounds and some other substances, in particular, polycyclic aromatic hydrocarbon--benzpyrene.

An increased incidence of malignant neoplasms among workers is often observed in a number of production facilities, whose technology is connected with the use of the above-mentioned chemical carcinogens. For example, A. V. Saknyn' and N. K. Shabynina report on a high mortality from lung and stomach cancer among workers engaged in nickel ore processing. Y. Konetzke describes 312 cases of occupational cancer caused by arsenic compounds. Y. Bittersohl cites data on the high blastomogenic activity of isopropyl oil at a plant in the United States and D. Lindars et al., having followed the fate of 40,867 workers, speaks of the high frequency of occupational lung cancer in the production of rubber with asbestos and of linoleum.

It was established that a number of industrial carcinogenic substances are present in the environment of settlements. People who have nothing to do with production are subjected to their effect. This circumstance cast doubt on the correctness of the concept of "spontaneous tumor" and gave rise to L. M. Shabad's statement on the "development" of an industrial hazard into a domestic hazard.

A high concentration of asbestos fibers, which got into the water supply system from industrial waste, was found in drinking water in the city of Duluth (United States) (T. Masson et al.). According to the data by G. Jacob, during autopsies asbestos fibers were found in lungs in 57.6 percent of the people in various countries who had nothing to do with asbestos production.

In a number of cases (city of Dzhetysay, Kazakh SSR) asbestos production waste is used as sand and gravel substitutes for filling roads and installing road signs and for other purposes. This leads to an artificial spread of asbestos dust far beyond the sphere of operation of the production waste of the asbestos combine. Along with this, joint studies by the Oncological Scientific Center of the USSR Academy of Medical Sciences (L. M. Shabad and associates) and the Kazakh Scientific Research Institute of Oncology and Radiology showed in an experiment on animals the pronounced blastomogenic activity of Dzhetysay asbestos, which intensified under a combined effect with tobacco smoke. At the same time, according to the data by G. Jacob, more than one-half of all the malignant mesotheliomas are due to the effect of asbestos dust.

Entering the environment, industrial refuse containing carcinogenic substances leads to an increase in the "background" of carcinogens in the atmosphere, water and soil, thereby, creating a situation unfavorable from the oncological point of view. For example, lip papillomas with signs of malignancy were found in fish caught near the discharge of the waste of industrial enterprises into the sea in California (F. Russel et al.). L. A. Zenina discovered a correlation between the frequency of cancer of the uterus among women and the proximity of their residence to chemical enterprises. S. Yukio et al. showed an increase in the mortality from lung, oral cavity, throat and liver cancer among the population living in the vicinity of metal-working plants.

The epidemiology of environmental carcinogens is characterized primarily by a difficult study of the effect of their action. The length of the latent period of cancer, migration of the population, complexity of recording the effect of various carcinogens and their doses and individual characteristics of the body--all these factors often hamper the determination of the true cause of a disease. Therefore, Haddow's words expressed at the Ninth International Cancer Congress are very convincing: "We are startled by the evidence that environmental factors are the causes of cancer in almost 90 percent of all the cases."

All the carcinogens surrounding man in the process of vital activity can be divided into two groups: 1) intentionally consumed by man (some types of food products and tobacco smoke) and 2) entering man's body without his knowledge (environmental pollution). The second group includes many chemical compounds, which can also be divided into purely industrial and industrial-domestic. Purely industrial carcinogens enter the environment with industrial refuse, while industrial-domestic carcinogens are formed both in industry and in homes. The latter are of special interest owing to their excessive spread in the environment. First of all, they include polycyclic aromatic hydrocarbons--substances well studied during the last decades. Being products of incomplete combustion, they can enter the atmosphere during the combustion of any organic compound. In this case preventive measures are reduced to the attainment of maximally complete combustion. Usually, the efficiency of such measures is established by the results of analysis of benzpyrene--the most widespread carcinogenic hydrocarbon.

Nitrosamines, whose blastomogenic activity is exceeded only by some alpha toxins, belong to the other major category of industrial-domestic carcinogens. A total of 90 out of the heretofore studied nitrosamines proved to be strong carcinogens (W. Lijinsky). These compounds are noted for their easy synthesis and can be formed from nitrites and amines both in the environment and in the body. Large quantities of predecessors of nitrosamines are contained in industrial waste, exhaust gases of motor transport, tobacco smoke and, simply, food products.

The basic tasks of the epidemiology of pollution of the environment with carcinogenic substances lies not only in establishing the increase in oncological morbidity, which at times is very difficult, as in forecasting cases of possible morbidity and its prevention. Individuals who under certain conditions more often develop malignant tumors are singled out into so-called "risk groups." They include groups having contact with carcinogens in industry, as well as residing near similar industrial facilities. The workers of "risk groups" should be subjected to periodic preventive examinations with provision for oncological alertness.

However, the main measure of prevention of an oncological disease lies in maximally restricting the contact with carcinogens when their full elimination from man's sphere of activity is unrealistic. When this problem was initially examined, there was no unanimous opinion owing to the lack of a (relative) threshold of action of carcinogenic substances. At present both hygienists and oncologists do not doubt the need for standardizing carcinogens on the basis of their oncogenous activity. The first steps in this direction have already been taken with regard to one of the carcinogens most widespread in the environment--benzpyrene. The establishment of maximum permissible concentrations for carcinogenic substances, apart from the legal basis, will serve as a criterion of the efficiency of preventive measures.

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## SCIENTISTS AND SCIENTIFIC ORGANIZATIONS

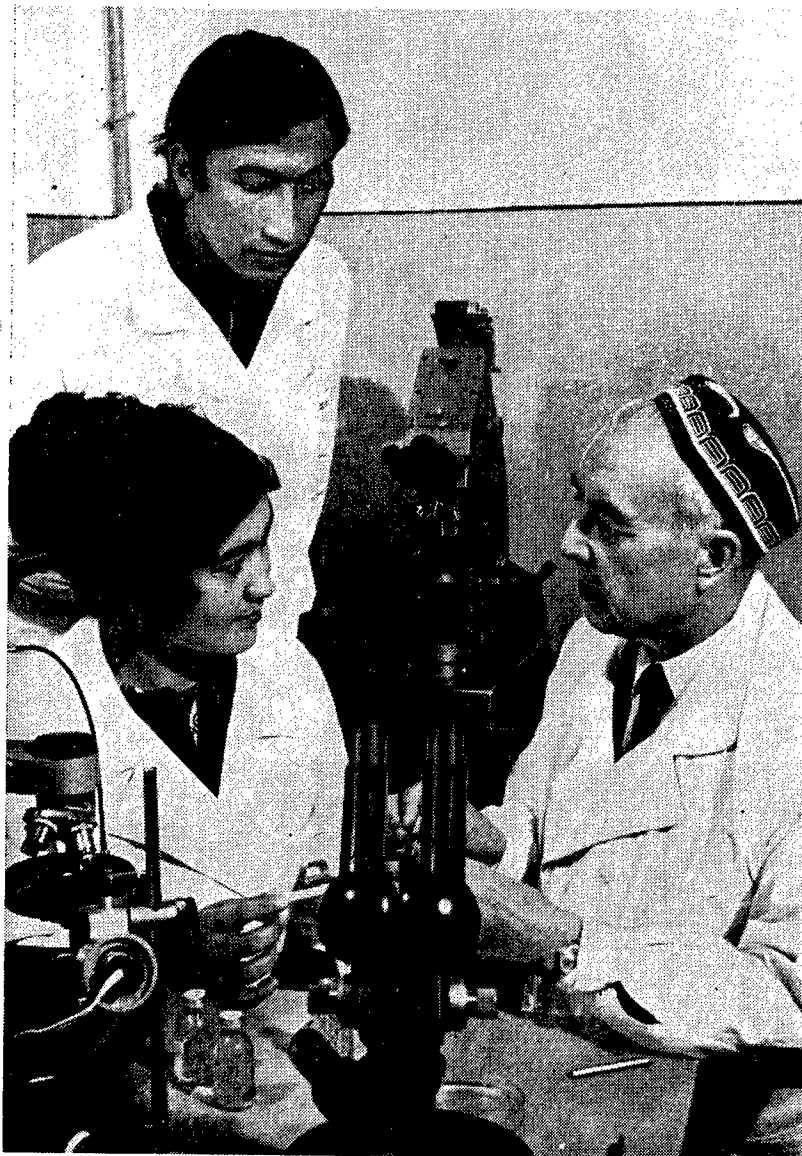
### 70TH BIRTHDAY OF A.M. MUKHAMEDIYEV

Tashkent EKONOMIKA I ZHIZN' in Russian No 6, 1977 p 80

[Text] The scientific community of Fergana marked recently the 70th birthday of Academician A.M. Mukhamediyev, one of the outstanding scientists of our republic and head of the Department of Zoology of Fergana State Pedagogic Institute. Honored Worker in Science A.M. Mukhamediyev is the author of 120 scientific works, two textbooks on zoology and three monographs. He is the teacher and mentor of a whole group of young scientists.

The photograph shows A.M. Mukhamediyev with his pupils M. Mamurova and B. Ishanov in the Laboratory of Hydrobiology and Ichthyology.

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